Global Hydrology Resource Center

# Data User Guide

# *GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2*

## Introduction

The GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2 dataset was collected from November 12, 2015 to December 19, 2015 during the GPM Ground Validation Olympic Mountains Experiment (OLYMPEX) field campaign held in the Pacific Northwest. This dataset is version -2 (V2) of the APR-3, an enhanced and upgraded instrument derived from the APR-2 used in previous field campaigns. APR-3 has the addition of W-band measurement capability, and scans cross-track from +/- 25° to the right and left of nadir. Ku-band, Ka-band, and W-band frequency Doppler measurements are made by APR-3 from the DC-8 aircraft at 10 km altitude during OLYMPEX. The APR-3 dataset files are in HDF-5 format with JPG format browse images. This dataset contains radar reflectivity, Doppler velocity for all bands, linear depolarization ratio at Ku-band, and normalized radar cross section measurements at Ka and Ku-bands.

**Notice:** This is Version 2, replacing the previous APR-3 dataset published by GHRC in 2017 (DOI for previous version: http://dx.doi.org/10.5067/GPMGV/OLYMPEX/APR3/DATA101). This APR-3 dataset is intended for research and users should contact the APR-3 team regarding data use, especially before publication or public presentation. This dataset is still undergoing validation and quality control. Users are invited to address questions and provide feedback to the Data Provider.

## Citation

Durden, Stephen L. and Simone Tanelli. 2018. GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2 [indicate subset used]. Dataset available online from the NASA EOSDIS Global Hydrology Resource Center Distributed Active Archive Center, Huntsville, Alabama, U.S.A. doi: http://dx.doi.org/10.5067/GPMGV/OLYMPEX/APR3/DATA201

## Keywords:

*NASA, GHRC, OLYMPEX, Washington, APR-3, DC-8, precipitation, radar, radar reflectivity, doppler velocity, NRCS, LDR, airborne*

## Campaign

The Global Precipitation Measurement (GPM) mission Ground Validation campaign used a variety of methods for validation of GPM satellite constellation measurements prior to and after launch of the GPM Core Satellite, which launched on February 27, 2014. The instrument validation effort included numerous GPM-specific and joint agency/international external field campaigns, using state of the art cloud and precipitation observational infrastructure (polarimetric radars, profilers, rain gauges, and disdrometers). Surface rainfall was measured by very dense rain gauge and disdrometer networks at various field campaign sites. These field campaigns accounted for the majority of the effort and resources expended by GPM GV. More information about the GPM mission is available at https://pmm.nasa.gov/GPM/.

One of the GPM Ground Validation field campaigns was the Olympic Mountains Experiment (OLYMPEX) which was held in the Pacific Northwest. The goal of OLYMPEX was to validate rain and snow measurements in mid-latitude frontal systems as they move from ocean to coast to mountains and to determine how remotely sensed measurements of precipitation by GPM can be applied to a range of hydrologic, weather forecasting, and climate data. The campaign consisted of a wide variety of ground instrumentation, radars, and airborne instrumentation monitoring oceanic storm systems as they approached and traversed the Peninsula and the Olympic Mountains. The OLYMPEX campaign was part of the development, evaluation, and improvement of GPM remote sensing precipitation algorithms. More information is available from the NASA GPM Ground Validation web site https://pmm.nasa.gov/olympex, and the University of Washington OLYMPEX web site http://olympex.atmos.washington.edu/.


Figure 1: OLYMPEX Domain
(Image Source: https://pmm.nasa.gov/OLYMPEX)

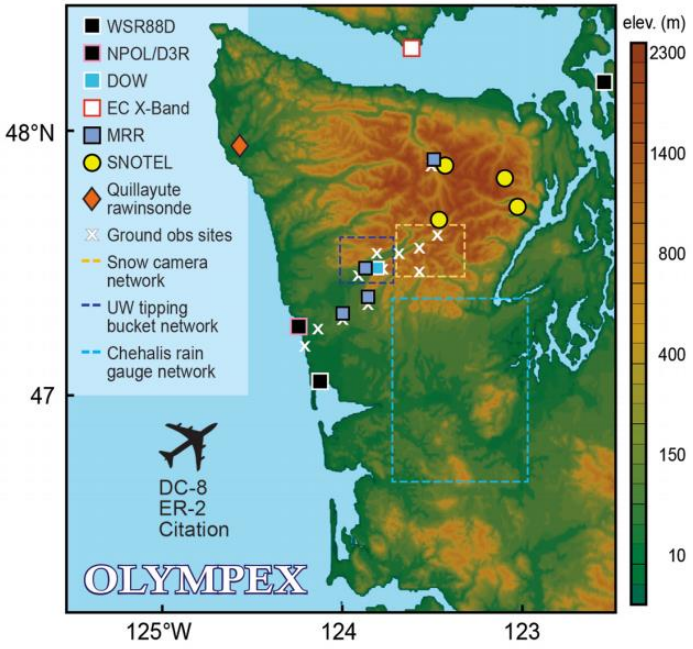


Figure 2: OLYMPEX Field Locations.
(Image Source: https://pmm.nasa.gov/OLYMPEX)

## Instrument Description

The Airborne Precipitation Radar 3rd Generation (APR-3) instrument is an enhanced version of the Airborne Precipitation Radar 2nd Generation (APR-2) instrument, which was successfully used in a number of previous GPM-GV field campaigns. The APR-3 performs simultaneous radar measurements of both like- and cross-polarized signals at 13.4 GHz

(Ka-band) and 35.6 GHz (Ku-band) and , for OLYMPEX, W-band measurements. The APR-3 instrument was mounted on the NASA DC-8 aircraft during OLYMPEX. As shown in Figure 3, the instrument was positioned to look downward and scan from side-to-side across the flight track from 25° to the left and right of nadir. The W-band data are collected with the same cross-track scanning geometry as used for Ku- and Ka-bands. This was accomplished by modifying the existing Ku and Ka feed to also allow for operation at W-band. A second W-band antenna was installed to provide the higher sensitivity needed for cloud sensing. This second W-band antenna has a larger aperture and only looked nadir (no side-to-side scanning) which allowed for more pulses to be integrated. For OLYMPEX, the data were acquired using one of the W-band antennas or the other, or sometimes both(simultaneous scanning and nadir). A flag is used to notify which antenna operated at any time. Radar sensitivity was not constant (mainly dependent on the pulse length). Users not familiar with the weather radar equation and APR-3 data should contact the APR-3 team to support data interpretation.

Users should refer to more detailed information about the APR-3 instrument operation in the Data provider documentation.

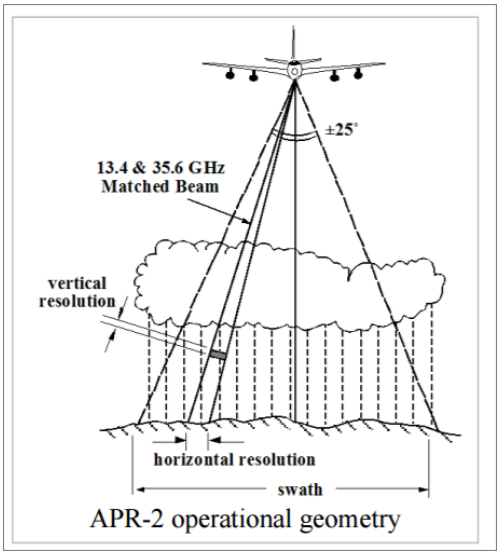

Figure 3: APR-2 (predecessor to the APR-3) operational geometry

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## Data Characteristics

The GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2 data files are available in HDF-5 format with browse imagery available in JPG format. These data are at a Level 2 processing level. More information about the NASA data processing levels are available on the NASA Data Processing Levels website. Table 1 shows the characteristics of the data files. The dataset contains only actual OLYMPEX flight data. Instrument testing and aircraft ferry to study region data are not included.

Table 1: Data Characteristics

| Characteristic | Description |
|---|---|
| Platform | Douglas DC-8 (DC-8) |
| Instrument | Airborne Precipitation Radar 3rd Generation (APR-3) |
| Projection | Equirectangular |
| Spatial Coverage | N: 49.432 , S: 46.171, E: -122.026, W: -129.140 (Washington) |
| Spatial Resolution | 800 m horizontal resolution at 10 km altitude, 60 m range resolution |
| Temporal Coverage | November 12, 2015 - December 19, 2015 |
| Temporal Resolution | Per flight: <less than 15 minutes |
| Sampling Frequency | 1.8 seconds |
| Parameter | Radar reflectivity, Doppler velocity, linear depolarization ratio |
| Data Provider Version # | 2.4 |
| Processing Level | 2 |

## File Naming Convention

The GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2 has the file naming convention shown below. These data are available in HDF-5 format with browse imagery available in JPG format.

**Data files:** olympex_apr3_YYYYMMDD_hhmmss_R2_***.h5
**Browse files:** olympex_apr3_YYYYMMDD_hhmmss_R2_***.jpg

Table 2: File naming convention variables

| Variable | Description |
|---|---|
| YYYY | Four-digit year |
| MM | Two-digit month |
| DD | Two-digit day |
| hh | Two-digit hour in UTC |
| mm | Two-digit minute in UTC |
| ss | Two-digit second in UTC |
| *** | KUsKAs: Ku- and Ka-band radar data obtained in scanning mode<br>Ws: W-band data obtained via scanning only<br>Wns: W-band data obtained via scanning and nadir modes |
| .h5 | HDF-5 format |

| | |
|---|---|
| .jpg | Joint Photographic Experts Group format |

## Data Format and Parameters

The GPM Ground Validation Airborne Precipitation Radar 3rd Generation (APR-3) OLYMPEX V2 data files are available in HDF-5 format with browse imagery available in JPG format. The browse images do not correlate to just one data file, but rather cover a specific time period that may encompass multiple data files. Browse images show data from various channels and the ground track of the DC-8 for the data displayed in the plots. More information about these data files, as well as the browse imagery, is available in the Data provider documentation.

This is Version-2 (also referred to as Release 2 in data provider documentation) of the APR-3 OLYMPEX dataset. Improvements consist of

- HDF-5 file format instead of HDF-4
- Improved Doppler processing and calibration

Each file contains the following sub-structures:

- lores: measurements at a lower resolution (Table 3)
- params_KUKA: parameters of APR-3 (Table 4)
- params_W: parameters of Airborne Cloud Radar (ACR) (Table 5)
- postEng_cal: Calibration shifts applied

Table 3: lores Data Fields

| Field Name | Description | Unit |
|---|---|---|
| alt3D | Altitude of each resolution bin | m |
| alt_nav | From aircraft or MMS navigation files | m |
| beamnum | Ray number within a scan | - |
| drift | Aircraft drift from aircraft or MMS navigation files | degrees |
| gsp_mps | Aircraft ground speed | m/s |
| isurf | Index of radar range bin intersecting surface (starting from 0) | - |
| lat | Latitude of the aircraft | degrees |
| lat3D | Latitude of each resolution bin | degrees |
| ldr14 | Linear Depolarization Ratio at Ku band | dB |
| ldr35 | Linear Depolarization Ratio at Ka band | dB |
| lon | Longitude of the aircraft | degrees |
| lon3D | Longitude of each resolution bin | degrees |
| look_vector | From navigation files | - |
| look_vector_radar | From APR-2 surface echo in scanning channels | - |
| path_vals | 15 parameters pertaining each beam - these are intermediate products – not recommended for Science use: | - |

| | | |
|---|---|---|
| | 1 = max Z Ku<br>2 = max Z Ka<br>3 = ZKu 1km range above isurf<br>4 = LDRKu 1km range above isurf<br>5 = ZKa 1km range above isurf<br>6 = LDRKa 1km range above isurf<br>7 = vKu 1 km range above surf (pre-correction)<br>8 = Pt Ku copol (cal loop)<br>9 = Pt Ku cxpol<br>10 = Pt Ka copol<br>11 = Pt Ka cxpol<br>12 = range bin max ZKu<br>13 =range bin max ZKu<br>14 = range bin ZKu @ 1 Km altitude<br>15 = range bin ZKu @ 1 Km altitude | |
| pitch | Aircraft pitch from aircraft or MMS navigation files | degrees |
| roll | Aircraft roll from aircraft or MMS navigation files | degrees |
| s095s | Surface NRCS (W band, scanning) | dB |
| scal_date_ACR | Airborne Cloud Radar (ACR) file date/time [YYYY,MM,DD,hh,mm,ss]<br>YYYY: Four-digit year<br>MM: Two-digit month<br>DD: Two-digit day<br>hh: Two-digit hour in UTC<br>mm: Two-digit minute in UTC<br>ss: Two-digit second in UTC | - |
| scal_date_APR | APR file date/time [YYYY,MM,DD,hh,mm,ss]<br>YYYY: Four-digit year<br>MM: Two-digit month<br>DD: Two-digit day<br>hh: Two-digit hour in UTC<br>mm: Two-digit minute in UTC<br>ss: Two-digit second in UTC | - |
| scantime | Beginning of scan since January 1, 1970 | s |
| sequence | Ray number within the file | - |
| surf_vals | 8 Measured parameters pertaining the surface:<br>1 = NRCS Ku [dB]<br>2 = Surface LDR Ku [dB]<br>3 = NRCS Ka [dB] | - |

| | | |
|---|---|---|
| | 4 = LDR Ka [dB]<br>5 = surface Doppler velocity Ku [m/s]<br>6-8 = not used | |
| surface_index* | Preliminary surface classification index | - |
| v_surf | Instrument measured surface Doppler velocity | m/s |
| v_surfdc8 | Apparent surface Doppler velocity | m/s |
| vel14c | Mean Doppler Velocity dealiased and from Ku- and Ka-band | m/s |
| z95s | Reflectivity at W band, Cross-track scanning (HH) scanning channel | dBZ |
| zhh14 | Radar Reflectivity at Ku-band | dBZ |
| zhh35 | Radar Reflectivity at Ka-band nadir port | dBZ |

*See Table 7

Table 4: params_KUKA Data Fields

| Field Name | Description | Unit |
|---|---|---|
| AntRetraceTime_s | Antenna retrace time | s |
| AntScanLeft_deg | Antenna scan left-limit | degrees |
| AntScanRight_deg | Antenna scan right-limit | degrees |
| AntScanTime_s | Scan time for antenna | s |
| CalVersion | Calibration version (obsolete) | - |
| Fixed_Ka_Pt | Fixed Port used for Ka Tx/Rx | - |
| Ka_Port | Port used for Ka Tx/Rx | - |
| Nbeams | Number of rays in each scan | - |
| Nbeams_data | Number of rays (per scan) with radar transmitting | - |
| Nbin_per_ray | Number of range bins in the ray | - |
| Npuls_avge | Number of pulse averaged by Wildstar board | - |
| Nscan | Number of scans in the file | - |
| PRF_Hz | Instrument pulse repetition frequency | Hz |
| pulselen_us | Instrument pulse length | us |
| range0_m | Distance of the first radar range bin from aircraft | m |
| Range_Size_m | Vertical resolution of range bin | m |
| Rx_atten | RX attenuation in reception: internal Cal parameter | dB |
| Tx_Atten | RX attenuation in emission: internal Cal parameter | dB |

Table 5: params_W Data Fields

| Field Name | Description | Unit |
|---|---|---|

| | | |
|---|---|---|
| Bandwidth_Eff_MHz | ACR effective bandwidth | MHz |
| CalVersion | Calibration version | - |
| integration_s | ACR integration time | s |
| iStartW | Range bin of where the center of the Tx event is recorded (i.e., range bin corresponding to range zero) | - |
| npulse_hh95 | Number of pulses averaged in scanning mode (hh) | - |
| npulse_vv95 | Number of pulses averaged in nadir-only mode (vv) | - |
| PRF_Hz | ACR pulse repetition frequency | Hz |
| pulselen_us | ACR pulse length | us |
| range0_m | Distance of the first radar range bin from aircraft | m |
| Range_res_m | Length of pulse (vertical resolution) | m |
| Range_Size_m | Length of range bin (vertical sampling) | m |
| slave_mode | ACR operation mode:<br>0 = stand-alone<br>1= slaved mode | - |
| Vnyq | Nyquist velocity | m/s |

Table 6: postEng_cal Data Fields

| Field Name | Description | Unit |
|---|---|---|
| s0hh14 | Calibration shifts for Radar reflectivity at Ku-band | - |
| s0hh35 | Calibration shifts for Radar Reflectivity at Ka-band nadir port | - |
| s0hh95 | Calibration shifts for Radar Reflectivity at W-band | - |
| zhh14 | Radar reflectivity at Ku-band | dBZ |
| zhh35 | Radar Reflectivity at Ka-band nadir port | dBZ |
| zhh95 | Radar Reflectivity at W-band | dBZ |

Table 7: Values for surface index

| Value | Description |
|---|---|
| 0 | Rough land |
| 1 | Ocean (level flight) |
| 2 | Ocean (roll maneuver) |
| 3 | Flat land (level flight) |
| 4 | Flat land (roll maneuver) |
| 5 | Antenna not scanning (unknown surface) |

## List of flights and datasets: OLYMPEX

Only local science flights (Nov 12-Dec 19) are included in the current release.

| # | Date | Observation | Notes |
|---|---|---|---|
| 1 | 2015, Nov 5 | Engineering Flight in California/Pacific Ocean | Not available in release 2.1 |
| 2 | 2015, Nov 10 | Transit to Lewis-McChord, WA | Not available in release 2.1 |
| 3 | 2015, Nov 12 | First local science flight | Prefrontal flow on Olympics |
| 4 | 2015, Nov 13 | Same system as Nov 12, frontal passage | Large accumulations of precip |
| 5 | 2015, Nov 14 | Precipitation ahead of a developing frontal wave | Collected Ku/Ka only 1715Z to 2017Z; no W-band |
| 6 | 2015, Nov 18 | Shallow post-frontal conv | Isolated cells below anvil |
| 7 | 2015, Nov 23 | Approaching weak trough | Observed light stratiform precip |
| 8 | 2015, Nov 24 | Continuation of Nov 23 system | Some postfrontal clouds |
| 9 | 2015, Nov 25 | Clear air calibration | Land survey, circles over ocean w/sonde |
| 10 | 2015, Dec 1 | A weak trough/front | Extensive stratiform precipitation modified by topography |
| 11 | 2015, Dec 3 | Complex baroclinic system | Orographically enhanced rain over land; underflew GPM, center of DPR swath |
| 12 | 2015, Dec 4 | Post-frontal | Isolated cells |
| 13 | 2015, Dec 5 | Broad frontal system | Stratiform with embedded convection; W timing issues; W not in this release |
| 14 | 2015, Dec 8 | Orographic enhancement of atmospheric river | APR3 acquired data over portion of GPM swath, likely clear |
| 15 | 2015, Dec 10 | Occluded front and post-frontal | Variety of precipitation, convection |
| 16 | 2015, Dec 12 | Occluded front and warm sector | Primarily stratiform precipitation |
| 17 | 2015, Dec 13 | Post-frontal | Convection |
| 18 | 2015, Dec 18 | Occluded front | Stratiform and convection |
| 19 | 2015, Dec 19 | Post-frontal; last local sci flt | Isolated cells, GPM DPR underflight |
| 20 | 2015, Dec 20 | Transit back to Palmdale | Not available in release 2.1 |

## Algorithm

The best resources for the algorithms used to process APR-3 data are Sadowy et al., 2003 and Tanelli et al., 2006.

## Quality Assessment

External calibration was used for all products. Reflectivity measurements should be considered reliable to within ±3 sigma.

The alt_radar and look_vector_radar pair is reliable only when flying over the ocean, and for OLYMPEX, provides a more accurate geolocation than the navigation-based pair.

The surface Doppler velocity (v_surf) was corrected for occasional aliasing and, in turn, was used to correct the Doppler measurements of precipitation for the bias introduced by the aircraft motion. This correction can be undone by adding the value of v_surf from vel14 at all range bins of every ray. This alternate correction may be of interest for the minority of data collected over land where the v_surf estimate is more prone to errors, or for data collected during sharp maneuvers by the DC-8.

The surface index is estimated by analyzing Ku and Ka surface returns, such as roughness, angle dependence of the surface normalized radar cross section, apparent surface inclination, and LDR at nadir. This is estimated on a scan-by-scan basis. The most frequent misclassification is ocean being classified as flat land.

Occasionally, high lateral winds may cause the Doppler measurements to be aliased. Doppler measurements should be corrected to account for a maximum unambiguous velocity of ±27.5 m/s. Also, correction for aircraft motion is less reliable when the aircraft was maneuvering or was affected by turbulence or was over land.

The term 'beams' and 'rays' are considered to be the same. No data values can appear as -99.99, as well as -9999, due to scaling by 100. The 'Zhh35' field has -32768 as missing data instead of -9999. For the 'surface_index', a values of 7 indicates no surface echo, as typically found in bean 24, which is noise-only. Finally, the W-band Port value in the file header, which serves as the flag indicating the absence or presence of the W-band reflectivity arrays 'zhh95' and 'zvv95', has a description of "flag_Wvv*10 + flag_Whh", where 'flag_Wxx' is 0 if absent or 1 if present, but less than half of the scans, or 2 which implies Whh is present in a majority of the scans and Wvv is absent in all of the scans. If Wvv were also present in most of the scans, the value would be around 22.

More information about the quality assessment for this dataset can be found in the Data provider Documentation.

## Software

These data are available in HDF-5 format, so no software is required. However, Panoply or HDFView can be used to easily view these data.

## Known Issues or Missing Data

A list of all known problems are listed in the Data provider Documentation. We refer users to this document. Please note, if there are missing data within a file, it is replaced by -9999.

The radar sensitivity was not constant (mainly dependent on the pulse length). Users not familiar with the weather radar equation and APR3 data should contact the APR3 team to support data interpretation

The Altitude and Look Vector are provided in two estimates: alt_nav and look_vector. These are calculated relying on DC-8 navigation information. Alt_radar and look_vector_radar are calculated relying on the observed surface return in Ku- and Ka-band data. The alt_radar and look_vector_radar pair is reliable only when flying over the ocean, and, in this case, provides a more accurate geolocation than the navigation-based pair.

## References

Sadowy, G. A., Berkun, A. C., Chun, W., Im, E., & Durden, S. L. (2003). Development of an advanced airborne precipitation radar.(Technical Feature). *Microwave Journal*, 46(1), 84-93. https://airbornescience.nasa.gov/sites/default/files/documents/pr2-mwj.pdf

Tanelli, S., S. L. Durden, and E. Im, (2006): Simultaneous Measurements of Ku- and Ka-band Sea Surface Cross-Sections by an Airborne Radar. *IEEE Geoscience and Remote Sensing Letters*, 3(3), 359-363. doi: https://doi.org/10.1109/LGRS.2006.872929

## Related Data

All data collected during the OLYMPEX field campaign should be considered related data sets. To locate other OLYMPEX data, use the GHRC search tool HyDRO 2.0 with the search term OLYMPEX. The APR-3 is related to the APR-2 instrument flown on experiments such as GRIP and NAMMA. To locate previous APR-2 data, use the GHRC search tool HyDRO 2.0 with the search term 'APR-2'.

## Contact Information

To order these data or for further information, please contact:

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Created: June 14, 2018